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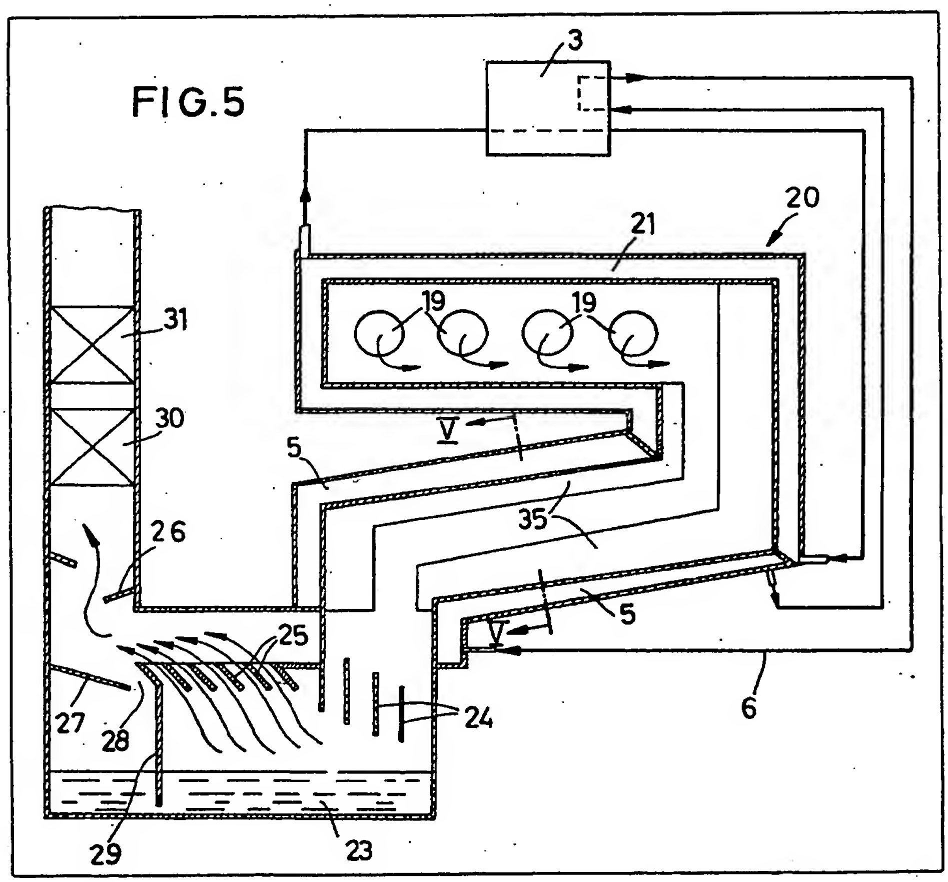
(54) A method and apparatus for purifying the exhaust gases of an internal combustion engine

(57) A method of purifying exhaust gases from an internal combustion engine such as a diesel engine by cooling the exhaust gases below their dew point and then separating out the liquid produced and the solid particles contained in the exhaust gases. Apparatus for performing the method comprises an exhaust duct (19) having a cooling surface (35) connected to a coolant circuit (21) of, for example a refrigerator (3), and a liquid separator (23),(24),(25). Filters (30)(31) having absorption agents are used to separate out further the solid particles.

FIG.5



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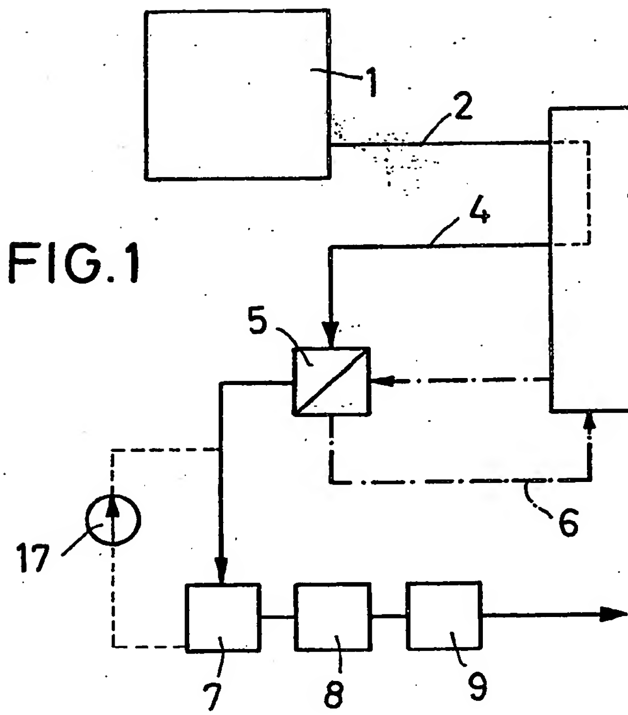

FIG.1

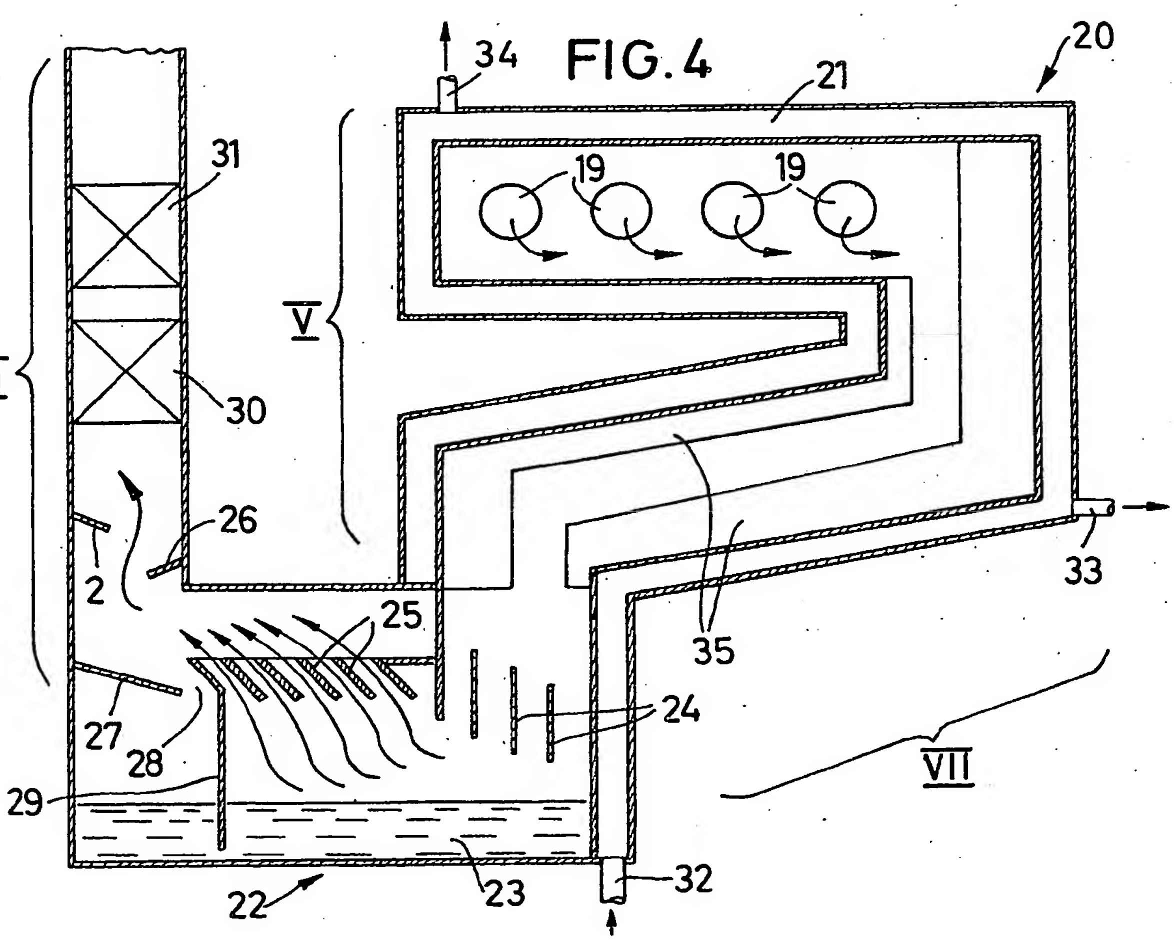

FIG.4

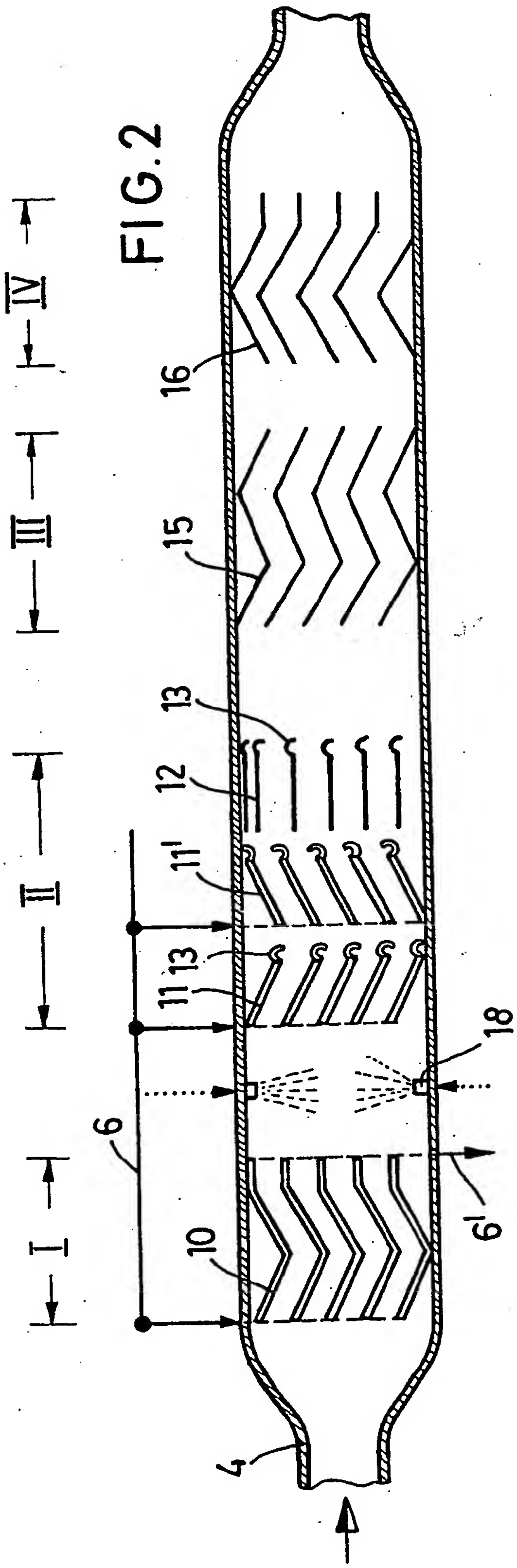

FIG.2

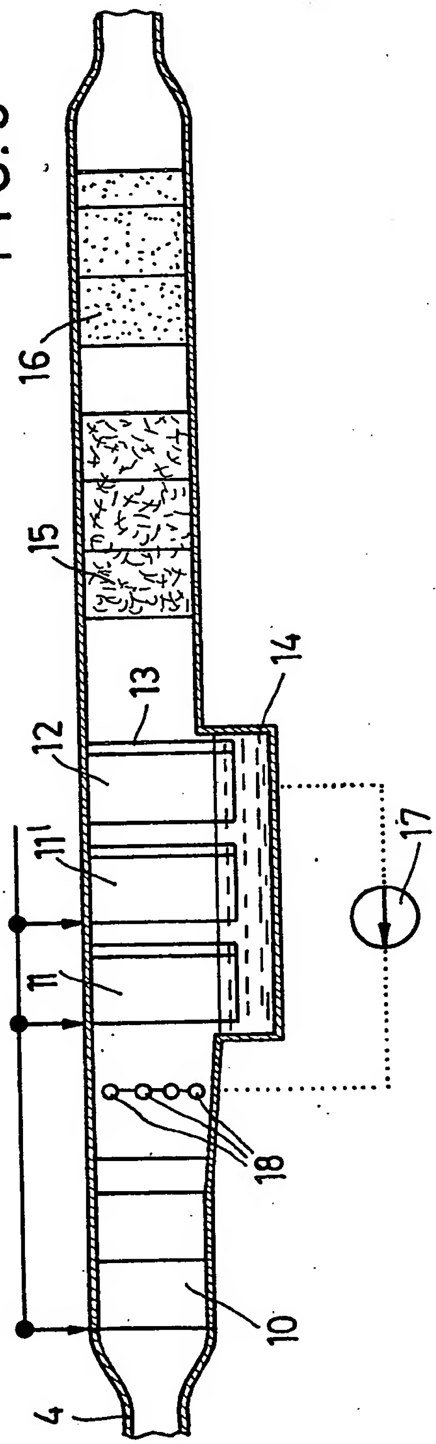

FIG.3

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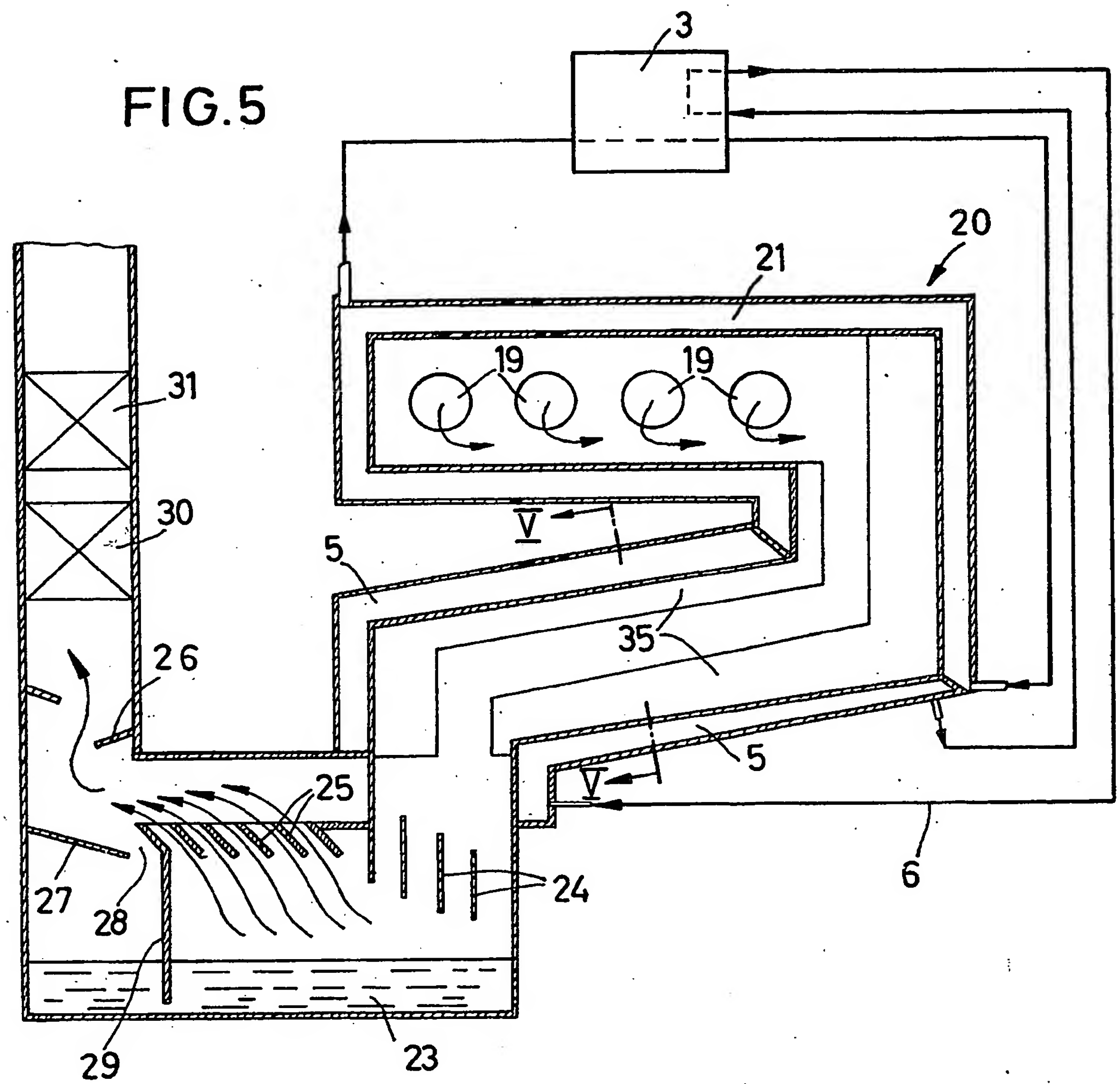
FIG.5



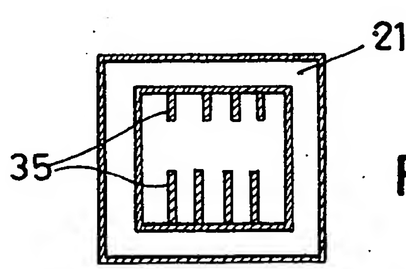


FIG.5a

SPECIFICATION

A method and apparatus for purifying the exhaust gases of an internal combustion engine

This invention relates to a method and apparatus for purifying the exhaust gases of an internal combustion engine, more particularly a diesel engine for use underground.

When using internal combustion engines, more particularly diesel engines, the exhaust gases produced by such engines present a number of problems. Thus for example in coal mining it is absolutely necessary, for reasons of safety against fire damp, for the gases to be cooled to such an extent that a maximum temperature of about 150°C is not exceeded at the exhaust pipe. Moreover for underground working in general the loss-generated heat given off by the internal combustion engine presents a further problem as regards mine ventilation, since at a rough estimate approximately 4 m^3/h of air per installed horse power has to be made available additionally underground. In addition to the matter of temperature, the deleterious substances contained in the exhaust gases, more particularly the gaseous deleterious substances, present further problems, which should be eliminated as far as is possible having regard to the conditions under which personnel have to work underground. Hitherto, safety against fire damp has been provided by spraying water into the exhaust gas pipe and then conducting the exhaust gases through a water seal, but this does not really allow adequate separation of deleterious gaseous substances from the exhaust gases. The known procedure also has the disadvantage that the known apparatus requires much maintenance and tends to develop faults, requires considerable space, and cannot remove some undesirable substances such as, for example, CO and CO_2.

The invention has as its object to provide a method and apparatus for cleaning exhaust gases from internal combustion engines, more particularly diesel engines.

This object is achieved according to the invention by cooling the exhaust gases below their dew point, and separating out the liquid produced and at least the solid particles contained in the exhaust gases. In addition to the advantage of improved safety against fire damp by lowering the exhaust gas temperatures, there is a further advantage of removing from the exhaust gases through the condensed-out water contained in the exhaust gases at least a proportion of the deleterious gaseous substances which are water-soluble or react with water, primarily the sulphur fractions coming from the fuel, and a number of nitrogen oxides. Together with the liquid droplets which are produced it is also possible to separate-out at least in part solid particles which are also contained in the gases, including soot particles. As a result there is already a considerable decrease in the pollution of the environment by harmful substances. A reduction of the exhaust gas temperature to about 130–150°C is already adequate.

Depending on the quantity of deleterious substance fractions, of water-soluble type or reacting with water, in the exhaust gases and on the quantity of water vapour contained in the exhaust gases, it may be advantageously additionally to spray liquid, more particularly water, into the flow of exhaust gases, in order to have a sufficient quantity of water available for the fixing of the relevant deleterious substance fractions. An additional advantage of spraying liquid into the flow of exhaust gases is firstly that there is a cooling effect in known manner so that the cooling power to be applied for cooling the exhaust gases is somewhat reduced, and secondly that through the increase in the proportion of liquid in the exhaust gas the degree of separation achievable by the liquid separator used can be improved as a result of the formation of relatively large droplets of liquid.

In further development of the invention it is proposed that after separating-out the liquid and solid particles the exhaust gases are brought into contact with at least one sorption agent, to separate further, deleterious gaseous substances out of the exhaust gases. If suitable sorption agents are used it is possible to remove from the exhaust gases in this way further deleterious gaseous substances which are not water-soluble and do not react with water. Thus for example the hydrocarbon compounds contained in the exhaust gas can be removed to a very great extent from the exhaust gases by means of adsorption, for example by contact with activated carbon. CO and CO_2 can be removed very effectively from the exhaust gases by use of chemisorption by the employment of suitable chemically active substances with which the exhaust gases are brought into contact.

In a preferred form of the method according to the present invention it is proposed that the cooling of the exhaust gases is effected at least partially by the heat exchanger surface of the discharge element of an absorption-type refrigerating machine. It is advantageous if the exhaust gases are cooled below their dew point with at least a portion of the cold flow produced in the absorption refrigerating machine. This method has the advantage that no additional energy is needed for producing the "cold" required for cooling the exhaust gases, and instead the heat resulting from losses which is contained in the hot exhaust gases is used for the production of cold energy and a cooling of the exhaust gases is already effected by the removal of heat in the discharge element. By this procedure it is possible to cool appropriately the exhaust gases which

are produced in the case of a given load with a temperature of, say, 430°C. Moreover, with at least a portion of the cold flow produced in the absorption refrigerating machine, load-dependent control of the cold flow required for cooling the exhaust gases being possible here also, the temperature of the exhaust gases can be further reduced, for example to 65°C and below. This ensures that the sorption agents used are not destroyed or thermally disintegrated by too high temperatures. It is also possible as a result to adjust the exhaust gas temperature in such a manner, possibly by suitable automatic control, that the most advantageous reaction temperature is set, for example, for chemisorption in the filter region. This should be expedient with fixed temperature setting at least for the main load range of the engine.

The invention also relates to apparatus for carrying out the aforementioned method in an internal combustion engine, more particularly a diesel engine, by arranging in the exhaust gas duct of the internal combustion engine at least one cooling surface connected to a liquid separator, said surface communicating with at least one coolant circuit. This ensures that the condensate forming at least on a portion of the cooling surface is removed from the gas flow. If a plurality of separate cooling surfaces are provided, different coolant circuits possibly with various coolants, for example, water and refrigerants can be provided. For example one coolant circuit can supply a "basic load" whereas the second and any further circuits can be used for regulating the exhaust gas temperature. With suitable construction of the liquid separator it is also possible to remove from the exhaust gases solid particles, for example soot particles, together with the liquid particles contained in such gases, so that any downstream sorption filters are not fouled by liquid and/or soot. In accordance with a preferred embodiment of the invention the cooling surfaces are connected to a refrigerant circuit of an absorption refrigerating machine, a high and, where appropriate, regulatable cooling power can be achieved whilst requiring a modest amount of space. This allows such apparatus to be installed in a vehicle driven by an internal combustion engine, for example an underground locomotive or the like, without loss of shaft power.

A nozzle arrangement for the spraying-in of liquid, more particularly water may be provided at least upstream of the liquid separator considered in the direction of gas flow. It is advantageous to spray additional liquid into the exhaust gas duct if the water vapour content in the exhaust gases is not sufficient to remove adequately from the exhaust gases the deleterious gaseous substances which they contain which are water-soluble or react with water. Atomising the water in the exhaust gas duct has the advantage in this case that in addition to achieving an appropriate temperature reduction the taking-up of such exhaust gas constituents is also improved. Since the liquid separated from the flow of exhaust gases has to be collected particularly when spraying-in additional liquid, such as water, the solvent power of the quantity of liquid present for the deleterious substances to be separated is not fully used up, it is advantangeous by means of a pump to recycle back into the exhaust gas duct via the nozzle arrangement the liquid collected in the liquid collecting chamber of the liquid separator in order to keep the volume of liquid to be made available as small as possible.

Furthermore at least one sorption filter may be provided downstream of the liquid separator. Here it is advantageous to arrange the sorption agent in each case in an insert which is detachably fitted into the exhaust gas duct. In this way after the sorption agent is exhausted, after a number of working hours, the insert can be replaced and the entire apparatus made ready for operation again without difficulty with a few manipulations. Since on the one hand the throughflow resistance of the sorption filter formed by the sorption agent insert must be as low as possible, and on the other hand care has to be taken to ensure intensive contact of the gas flow with the sorption agent when the gas flows through the filter, the sorption agent is mounted on support surfaces about which the exhaust gases in the exhaust gas duct flow preferably with multiple deflection of the exhaust gas flow.

Preferred embodiments of the invention will now be explained in more detail with reference to the accompanying drawings in which:

Figure 1 shows a flow chart of a method in accordance with this invention;

Figure 2 is a horizontal cross-sectional view of apparatus for carrying out the method;

Figure 3 is a vertical cross-sectional view of the apparatus shown in Fig. 2;

Figure 4 shows a further arrangement for carrying out the method;

Figure 5 shows an arrangement according to Fig. 4 but with cooling by a refrigerant, and

Figure 5a shows a cross-section taken on the line V–V of Fig. 5.

The embodiment described with reference to Fig. 1 is based on the use of a refrigerant as a cooling medium for cooling of the exhaust gases.

As is shown in the flow chart of Fig. 1, the exhaust gas conduit 2 of an internal combustion engine 1, for example a diesel engine, is taken through a heat exchanger surface, not shown in detail, of a discharge element of an absorption-type refrigerating machine 3. The exhaust gases conducted out of the discharge element of the absorption refrigerating machine are fed by way of a conduit 4 to an

exhaust gas cooling device 5 whose cooling surfaces are connected to the refrigerant circuit 6 of the absorption refrigerating machine. Since the thermal energy required for producing the refrigerant circuit is taken from the engine exhaust gases whose temperature may be in the order of 430°C, these gases already undergo cooling to for example 200°C before entering the exhaust gas cooling device 5 which is designed so that the exhaust gases are here deliberately cooled below their dew point causing the vapours contained in the exhaust gas to condense and form liquid which is removed from the gas flow. In this condensing operation the gas fractions which are water-soluble or react with water are also removed at the same time. Instead of the discharge element 3 and the exhaust gas cooling device 5 it is also possible to use a cooling device operated with water as coolant. Depending on the design of the apparatus, a combined cooling with water and refrigerant is also possible, as will be shown by means of one constructional example.

The liquid condensed out of the flow of exhaust gases is then removed from the exhaust gas flow by means of a liquid separator 7. Although, for simplicity, the flow chart shows an exhaust gas cooling device and a liquid separator as "separate" units, it should be appreciated that in actual practice at least a portion of the cooling surfaces have to have a liquid separating function at the same time since when the exhaust gases drop below their dew point in these regions of the cooling device some of the vapours contained in the exhaust gases are already precipitated as condensate on the cooling surfaces.

Connected downstream of the liquid separator are one or more sorption filters 8, 9 in which further deleterious substances in gas form can be removed. The particular sorption agent to be used will depend on the gas constituents which are to be separated out. Thus for example the sorption filter 8 can be constructed as an activated carbon filter with which hydrocarbons contained in the exhaust gases can be substantially removed from the exhaust gases. The sorption filter 9 is then provided with a sorption agent whereby CO and CO_2 for example can be removed from the exhaust gases by use of chemisorption.

Figs. 2 and 3 show in horizontal and vertical section a constructional example of apparatus for carrying out the above described method. The region I indicated in the horizontal section in Fig. 2 forms substantially the exhaust gas cooling apparatus, region II the liquid and solids separator, region III a first sorption filter and region IV a second sorption filter.

In this example of cooling apparatus, in the cooling region I the exhaust gas duct 4 is subdivided by a plurality of preferably zigzag-shaped lamellae or fins 10 situated parallel to one another. These fins and also the duct wall in this region are conveniently of hollow construction and connected via supply conduits 6 and discharge conduits 6' to a coolant circuit, for example the refrigerant circuit of a refrigerating machine. The construction of the cooling device depends substantially on the cooling surface required, the space available for accommodating the entire apparatus, etc. With a relatively flat duct it may be sufficient, depending on the requisite cooling power, to apply the coolant only to the duct walls, whilst the fins are made of solid material which is a good conductor of heat, and are connected in heat-conducting manner to the cooled duct walls. This system also can ensure the necessary removal of heat.

Instead of using fins for cooling, a multiple-tube cooling device could also be used to which the coolant is fed and whose small tubes have the exhaust gases flowing through them. However, the form of the cooling surfaces must be so chosen as to provide the least possible resistance to throughflow.

In region II, for liquid separation, a plurality of vertically arranged fins 11, 11' and 12 are arranged parallel to one another with fins 11, 11' at an inclination to the duct axis, the fins being provided at their outlet edge with a continuous gutter 13. The lower end of fins 11, 11' and 12 extends, as Fig. 3 shows, into a collecting chamber 14 for collecting the separated-out liquid. Since the separating fins 11 upstream of the gutter 13 have a large baffle surface area, it is convenient for this baffle surface also to be of hollow construction and connected in the coolant circuit, so that the separate fins also act as cooling surfaces. However, the arrangement must be made such as regards their cooling effect that even at full load the exhaust gases flowing through the duct reliably drop below their dew point before the last collecting gutter 13 of the fins 12 in the direction of flow. The last row of fins 12 does not have to be cooled but serves to separate out from the gas flow the liquid droplets not taken up in the fins 11', so that after the liquid separator the exhaust gases no longer contain substantially any liquid droplets.

In the sorption filter regions III and IV the sorption agents are applied to suitable support surfaces 15 and 16, which are so shaped as to ensure that all the exhaust gases come into contact with these surfaces, for example by making the support surfaces 15, 16 zigzag-shaped or corrugated to form narrow channels through which every volume particle of the exhaust gas flows on its way through each sorption filter region to come into contact once with the particular sorption agent concerned allowing the relevant deleterious substances to settle. Conveniently, sorption region III is constructed with an activated carbon layer as sorption agent, so that any liquid

droplets which may still be present in the exhaust gases and which cannot be precipitated are also taken up. The surfaces of sorption region IV are provided with a substance which chemically combines the CO and CO_2 constituents in the exhaust gases.

In each of sorption regions III and IV, the wall of the exhaust gas duct is constructed to be openable, so that after fixed numbers of working hours the surfaces carrying the sorption agents can be taken out and replaced by new ones. In this connection it is advantageous if the individual surfaces are secured in a frame, so that these can be quickly replaced as a complete unit. The constructional arrangement of the sorption filters is not limited to the example described.

The apparatus operates as follows:

The engine exhaust gases issuing from the discharge element of the refrigerating machine 3 at a temperature of, for example, 200°C are conducted over the cooling surfaces 10 and in so doing are cooled to such an extent that their temperature drops below their dew point. The vapours contained in the exhaust gases condense in the form of fine droplets, which are carried along by the exhaust gas flow into the separation region II. Owing to the deflection caused by the baffle surfaces of the separating fins in row 11, which may also be cooled, the droplets are precipitated on the baffle surfaces and are carried along by the flow into the collecting gutters 13 arranged at the rear edge of the fins. The liquid collects in the gutters 13, is held in the gutters 13 by the air turbulence caused, and flows downwards into the collecting chamber 14. The same operation is repeated at the fin rows 11', 12, so that the condensed-out droplets are substantially completely separated out from the flow of exhaust gases. Since the condensed droplets include deleterious gaseous substances which react with water or are water-soluble, more particularly sulphur dioxide and the water-soluble nitrogen oxide constituents, these deleterious substances are removed from the exhaust gases by way of the collecting gutters 13.

On passing through the sorption region III, which for example has activated carbon layers as sorption agent, substantially the hydrocarbon compounds are fixed by adsorption. Any liquid fractions which are still contained and which cannot be mechanically separated are also taken up on the activated carbon layer.

The CO and CO_2 constituents in the exhaust gases are then largely removed from the gases in sorption region IV by chemisorption with suitable sorption agents, and the gases blown out externally by way of a silencer.

If the quantity of liquid obtained through condensation is not sufficient to combine to the desired extent the deleterious gaseous substance fractions which are combinable with water, a suitable quantity of water can be sprayed into the exhaust gas duct 4 between the cooling region I and the separating region II as indicated in Figs. 2 and 3. To keep the quantity of water required for this purpose as small as possible, the liquid collected in the collecting chamber 14, is re-cycled by a pump 17. Since the collecting chamber 14 has to be emptied from time to time it does not add any substantial further burden on maintenance to fill the collecting chamber partly with water after it is emptied after an appropriate number of working hours, to have a suitable supply of liquid available right at the beginning of operations. However, this liquid supply need not be very large, since the water supply increases correspondingly because of the condensation of water vapour.

The liquid spraying also has a corresponding cooling action, so that for example cooling of the baffle surfaces of the rows of fins 11 can be dispensed with or the cooling surface in the cooling region I can be somewhat reduced, if this seems expedient for reasons of space. Spraying-in is effected for example through nozzles 18 which are arranged at the two sides at the duct wall. The arrangement described need not be so constructed, as shown in Figs. 2 and 3 that the individual regions I to IV are arranged directly following one another in the same duct cross-section. Whereas for functional reasons the regions I (cooling) and II (liquid separation) should be combined in one assembly as far as possible, it is quite possible to arrange the sorption regions III and IV at another location on the vehicle in accordance with constructional circumstances, and to connect them to the preceding region by a suitable connecting duct of small cross-section. This may even be of advantage by improving flow since a reduction in the duct cross-section downstream of the liquid separation region II allows for the reduction in volume caused by cooling and accelerates the flow of exhaust gases.

Whereas the arrangement described with reference to Figs. 2 and 3 is used preferably for internal combustion engines in static situations, owing to the somewhat complicated construction of the liquid separator, an arrangement will be described with reference to Fig. 4 by means of which the method according to the present invention can be used for internal combustion engines on vehicles. This arrangement is particularly advantageous for underground vehicles since in that case in addition to the power requirements for cooling and separation of harmful substances the further problem has to be considered of the small space available for fitting additional units. In the illustrated constructional form the gas outlet ports 19 of the individual cylinders, for example of a four-cylinder disel engine, open into an exhaust gas duct 20. The exhaust gas duct is of doublewalled construction forming a cooling jacket 21 with a coolant

flowing through the space between the inner and outer walls. A first region V of the gas duct 20 extends downwards so that the condensate forming when the exhaust gases cool can run off. In a second region VI the exhaust gas duct extends upwardly and at the lowest part of region VI is a liquid separating and collecting device 22 which is formed by a collecting chamber 23 into which the exhaust gases are introduced from above and from which they passed out in an upward direction with a sharp change of direction, so that droplets entrained with the exhaust gas flow are thrown out in the region where the direction of gas flow changes. Guide plates 24 are arranged in the downwardly directed duct region and deflecting plates 25 in the region of entry to the upwardly directed duct region VI. Droplet baffle plates 26, 27 may be provided in the entry region of the upwardly directed duct region VI, so that in the turbulence produced by these "dead spaces" in the flow any droplets still entrained are separated out and can enter the collecting chamber 23 by way of an aperture 28 and a runoff plate 27, the aperture 28 being shielded against gas throughflow by means of an intermediate wall 29.

In the duct region VI above the droplet baffle plates 26, 27 there are arranged sorption filters 30 and 31 by means of which particular deleterious substances can be removed from the exhaust gases in the same way as described with reference to Figs. 2 and 3.

Depending on the particular kind of use, the cooling water circuit of the engine can be used for cooling the exhaust gases, the cooling water in the region of the collecting chamber 23 entering the interior of the cooling jacket 21 through an opening 32, and flowing through said jacket in counter-current to the flow of exhaust gases. Some of the cooling water can be branched off from the cooling jacket and fed directly for cooling the engine. This is indicated by the outlet union 33. The remainder of the cooling water flows right through the cooling jacket and is discharged from one end thereof through a connecting union 34 to the engine cooling device or radiator. To increase the cooling surface, part of the inner walls of the downwardly extending exhaust gas duct may be provided with cooling ribs 35 which project into the exhaust gas flow and extend in the flow direction as shown in Fig. 5, so that there is an increase in the surface area about which the hot exhaust gases flow. If such ribs are provided, the lower ones, as shown in Fig. 5a, extend further into the gas flow than the upper ones. It is important that in the region where the temperature of the exhaust gases drops below their dew point at various loads on the engine there should be no horizontal duct portion, and that instead by provision of a suitable slope as is indicated for duct region VII a friction-free run-off of the condensing-out liquid is made possible.

The cooling jacket can also be supplied wholly or partly with a refrigerant instead of a water coolant. The arrangement can be such that the cooling jacket 21 in the high-temperature region, i.e. the region wherein the hot engine exhaust gases issue from the cylinders into the exhaust duct, serves as a heat exchanger surface of the discharge element of an absorption refrigerating machine 3, so that the thermal energy contained in the exhaust gases is used as heat energy for the operation of the discharge element. Since lowering the temperature of the exhaust gases in this way does not cool the gases below their dew point, the remaining portion of the exhaust gas duct is cooled with water as described hereinbefore. If a very considerable lowering of the exhaust gas temperature is desired, for example to about 20° to 30°C, then it is convenient if the lower region is also cooled by a refrigerant. This can be effected by using a portion of the "cold energy" produced in the absorption refrigerating machine for the purpose of cooling the exhaust gases, that is to say the cold refrigerant is conducted again through the cooling jacket in the appropriate region and thus takes up the heat contained in the exhaust gases. This is shown in Fig. 5, which corresponds to the flow chart used in Fig. 1.

The conducting of the exhaust gases from the flow technique point of view in the individual function regions, and also the constructional arrangements in the individual function regions is not limited to the illustrated constructional examples. More particularly in the region II (liquid separator) differently constructed liquid separators can be used. Generally, care must be taken so that resistance to throughflow of the exhaust gases does not impair the performance of the internal combustion engine.

CLAIMS

1. A method of purifying the exhaust gases of an internal combustion engine, by cooling the exhaust gases below their dew point, and separating out the liquid produced and at least the solid particles contained in the exhaust gases.

2. A method according to Claim 1, including spraying liquid into the exhaust gas flow.

3. A method according to Claim 1 or Claim 2, including passing the exhaust gases into contact with at least one sorption agent after the liquid and solids particles are separated out, in order to separate-out further deleterious gaseous substances from the exhaust gas.

4. A method according to Claim 1, 2 or 3, including utilising the heat exchanger surface of the discharge element of an absorption

refrigerating machine to at least partially cool the exhaust gases.

5. A method according to Claim 4, wherein the exhaust gases are cooled below their dew point with at least a portion of the cold flow produced in the absorption refrigerating machine.

6. A method of purifying the exhaust gases from an internal combustion engine substantially as described herein with reference to the accompanying drawings.

7. Apparatus for carrying out the method according to Claim 1 comprising an exhaust gas duct having at least one cooling surface, a liquid separator connected to the duct, and at least one coolant circuit connected to said surface.

8. Apparatus according to Claim 7 including a second coolant circuit connected to at least part of said surface and formed by the refrigerant circuit of an absorption refrigerating machine, said part of the cooling surface being formed by the heat exchanger surface of the discharge element of the refrigerator machine.

9. Apparatus according to Claim 7 or 8 including nozzles for spraying liquid into said duct upstream of the liquid separator as viewed in the direction of gas flow.

10. Apparatus according to Claim 9 wherein said liquid separator includes a liquid collecting chamber and said apparatus includes a pump to pump liquid from said chamber to said nozzles.

11. Apparatus according to any one of Claims 7 to 10 including at least one sorption filter downstream of the liquid separator as viewed in the direction of gas flow.

12. Apparatus according to Claim 11 wherein said filter includes a sorption agent detachably mounted in the exhaust gas duct.

13. Apparatus according to Claim 12 wherein the sorption agent is applied to support surfaces about which the exhaust gases in the exhaust gas duct flow, the surfaces being shaped to provide multiple changes of direction of the gas flow.

14. Apparatus according to any one of Claims 7 to 13 wherein the exhaust gas duct is surrounded over at least part of its length with a cooling jacket through which, in use of said apparatus with an internal combustion engine, water flows from the cooling water circuit of said internal combustion engine.

15. Apparatus according to Claim 14 wherein a portion of the wall of the exhaust gas duct is formed by the heat exchanger surface of the discharge element of an absorption refrigerating machine and is situated in the region of entry of the exhaust gases into the exhaust gas duct.

16. Apparatus according to Claim 14 or 15 wherein the exhaust gas duct, as viewed in the direction of flow of the exhaust gases, is directed substantially downwardly in a first duct region, the inner walls of the exhaust gas duct which are situated below in each case being arranged at least partially in inclined manner, and extends in an upward direction in a second duct region, and that the liquid separator is situated at the lowest zone between the first and second duct regions.

17. Apparatus according to Claim 15 including a sorption filter arranged in the second, upwardly directed duct region.

18. Apparatus for carrying out the method according to Claim 1 substantially as described herein with reference to Figs. 2 and 3 of the accompanying drawings.

19. Apparatus for carrying out the method according to Claim 1 substantially as described herein with reference to Figs. 4, 5 and 5a of the accompanying drawings.

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